Space Communications and Navigation Capability Roadmap

Public Outreach Workshop

Mayflower Hotel

Washington, D.C.

30 November 2004

Discussion Topics

- Background
- Organization Established to Address Communication & Navigation Roadmaps
- Process Being Used to Develop Roadmaps
- Plans & Progress to Date

Advanced Planning Roles & Responsibilities

- NASA Strategic Planning Council
  - Responsible for Agency-level strategic decisions; reviews and approves the NASA Strategic Plan
- NASA Operations Council
  - Responsible for integrated Agency tactical and operational activities; ensures timely and effective implementation of strategies approved by Strategic Planning Council
- Director for Advanced Planning
  - Develops input, options, and assessments for Strategic Planning Council
    - Overall Agency architecture, Agency-level requirements and flow-down process
    - Science/exploration/policy strategic roadmaps and capability roadmaps (with Directorates)
    - New initiatives and studies of strategic issues
- Associate Deputy Administrator for Systems Integration
  - Tracks and assesses integrated schedules for major Agency programs, identifies and monitors cross-Directorate program interdependencies

Management Structure and Products

Associate Dep. Administrator, System Integration
Mary Kicza
Director for Advanced Planning
Dr. Charles Elachi

Strategic Planning Council

NASA Operations Council

Senior Management Board

Advanced Planning and Integration Office

Bernie Seery, Mgr.
Doug Stetson, Deputy West Coast
Gary Martin, Deputy East Coast

Dep. Director, Adv. Planning (Policy)
• J. Wood

Administrative Staff

Architecture Integration
• B. Sponberg

Systems Integration

Human Cap./Instit. Integration
• J. Simpson

Budget Integration
• M. Abreu

Program Integration
• M. Tanner

Strategic Plan
• D. Shurr (B)

Advanced Planning

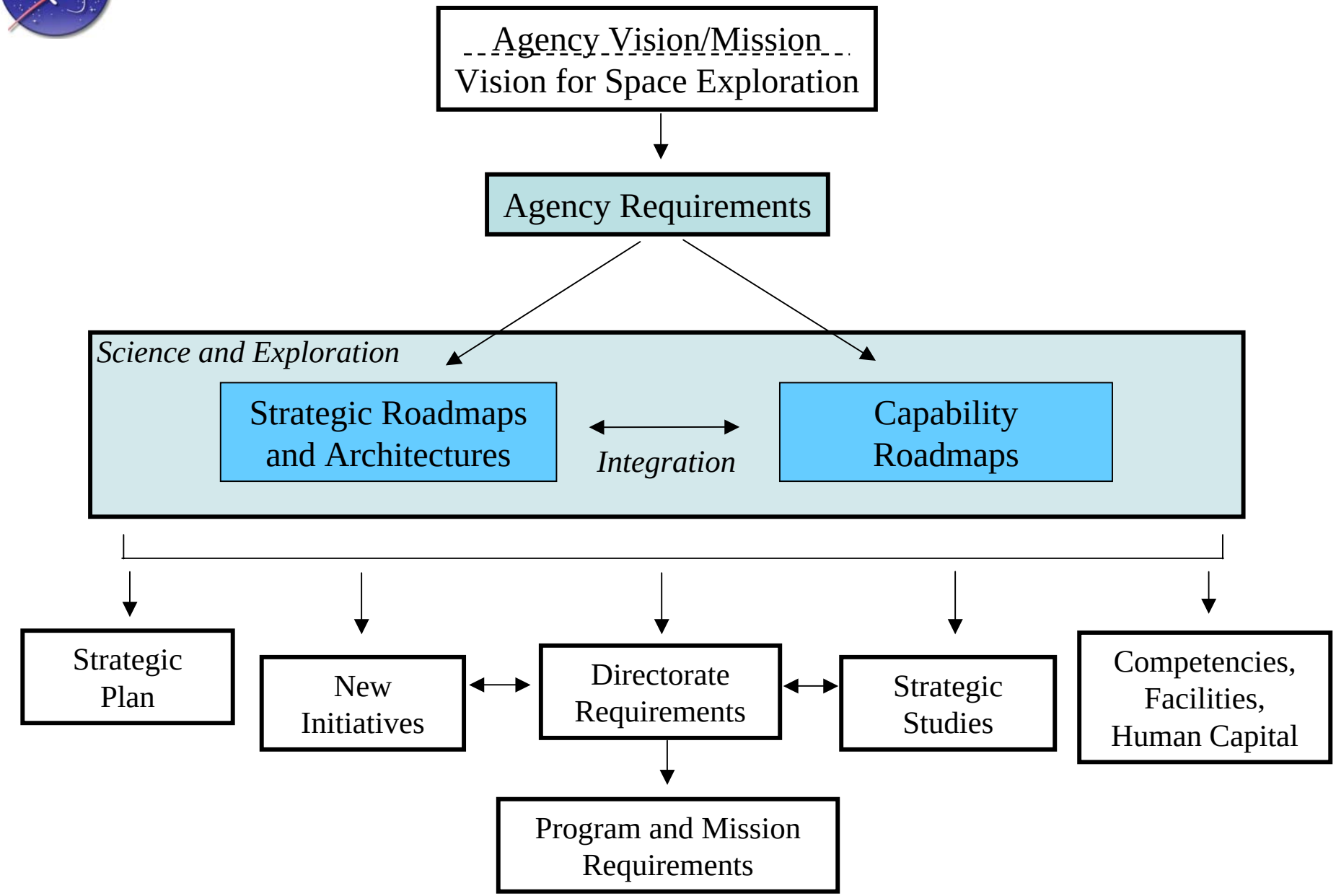
New Initiatives Process
• G. Martin (A)

External Strategy
• G. Martin

Strategic Roadmaps
• M. Allen (SMD)

Capability Roadmaps
• R. Willcoxon (KSC)

Product Hierarchy and Requirements Flow



NASA Exploration Level 0 Requirements

- *Mission Statement:* NASA shall advance U.S. scientific, technological, security, and economic interests through a robust human and robotic space exploration program.

(1) NASA shall implement a safe, sustained, and affordable robotic and human program to explore and extend the human presence across the solar system and beyond.

(1.1) NASA shall develop the innovative technologies, knowledge, capabilities, and infrastructures to support human and robotic exploration.

(1.2) NASA shall conduct a series of robotic missions to the Moon to prepare for and support future human exploration activities.

(1.3) NASA shall conduct human lunar expeditions to further science, and to develop and test new exploration approaches, technologies, and systems, including use of lunar and other space resources to

NASA Exploration Level 0 Requirements (continued)

(2) NASA shall acquire an exploration transportation system to support delivery of crew and cargo from the surface of Earth to exploration destinations and to return the crew safely to Earth.

(3) NASA shall complete assembly of the International Space Station, including the U.S. components that support U.S. space exploration goals and components provided by foreign partners, planned by the end of the decade.

(3.1) NASA shall focus use of the Space Shuttle to complete assembly of the International Space Station.

(3.2) NASA shall focus U.S. International Space Station research and technology on supporting space exploration goals.

(3.3) NASA shall separate transportation of crew and cargo to the International Space Station to the maximum extent practical

(4) NASA shall pursue opportunities for international participation to support U.S. space exploration goals.

(5) NASA shall pursue commercial opportunities for providing transportation and other services supporting the International Space Station and exploration missions beyond low-Earth orbit.

(6) NASA shall identify and implement opportunities within missions for the specific purposes of inspiring the nation.

Strategic Roadmaps and Architectures

Key elements of the process:

- Based on Level 0 requirements
- Roadmap teams chaired by senior NASA and non-NASA individuals
- Senior participants from key mission directorates and centers
- Guidelines for team membership - NASA/JPL/gov, industry, academia (1/3 each)
- Directorates/APIO provide guidance and data, facilitate meetings, participate on teams
- Centers provide technical support, coordinated by directorates/APIO
- Incorporate advisory committee input and roadmaps
- Open meetings(s) for broad community input
- Engage National Academy groups for input and reviews
- Integrate final roadmaps to form NASA architecture/strategic plan
- Implementation plans provide foundation for budget decisions, capability needs, infrastructure, human capital, center competencies, etc.

Strategic roadmaps should include the following elements:

- Broad science and exploration goals, priorities, recommended activities or investigations, and a summary of anticipated discoveries and achievements
- High-level milestones, options, and decision points
- Suggested implementation approach and mission sets
- Key dependencies on and relationships to other Strategic Roadmaps
- Identification of required capabilities, facilities, and infrastructure

Capability Roadmaps

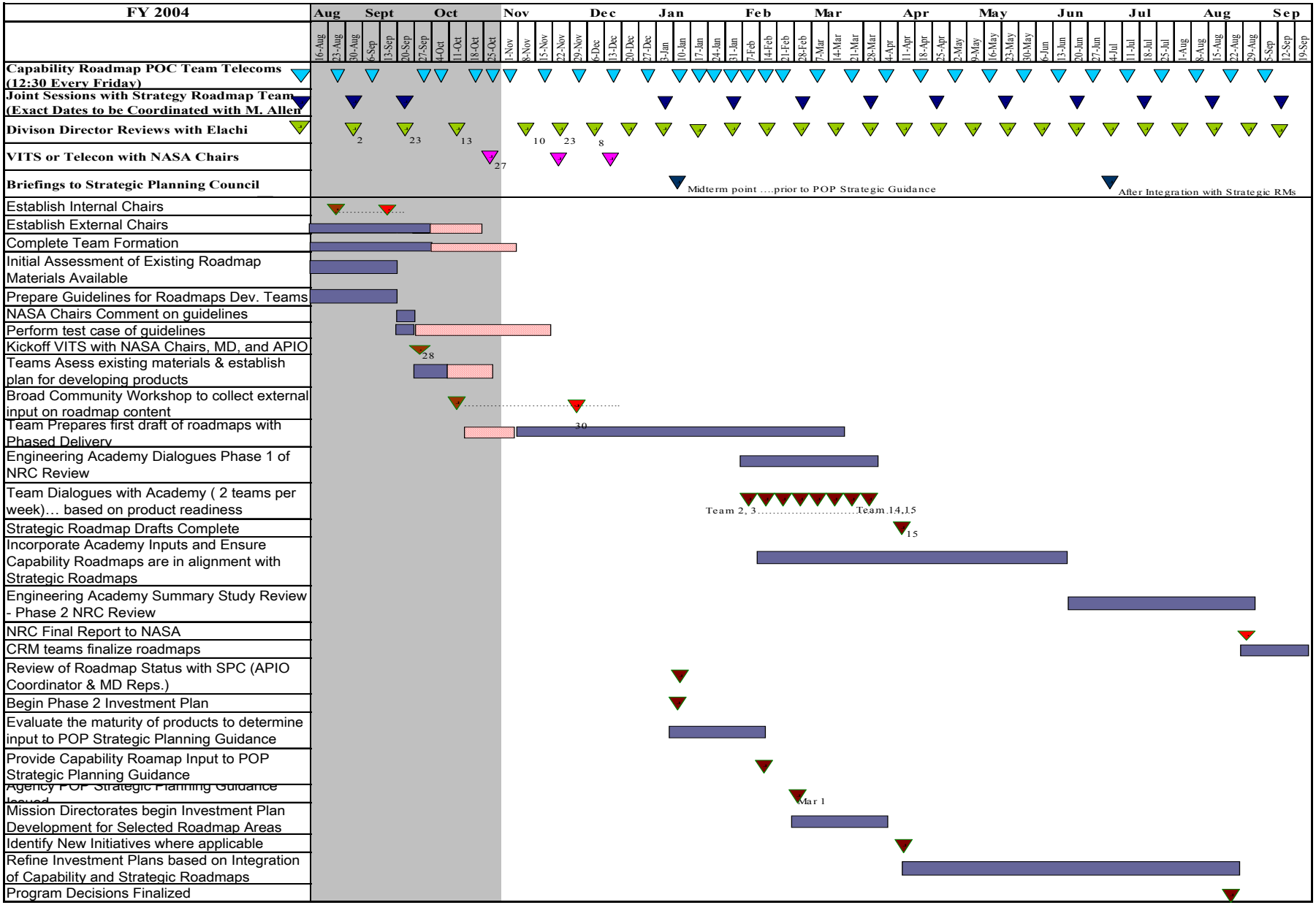
Key elements of process:

- Based on Presidential Commission recommendations and prior knowledge of mission and program needs
- Directorate leadership with APIO participation
- Develop common formats, guidelines, constraints
- Broad roadmap categories should be defined to encompass key technical areas - work with team chairs prior to first meeting
- Technical input derived from existing material, CRAI reports, etc.
- Teams led by technical experts (1 NASA/JPL, 1

Capability Roadmaps Recommended by the Presidential Commission

***Affordable heavy-lift capability**:* Technologies to allow robust affordable access of cargo, particularly to low-Earth orbit
***Advanced structures**:* Extremely lightweight, multi-function structures with modular interfaces, the building-block technology for advanced spacecraft.
***High acceleration, high life cycle, reusable in-space main engine**:* For the crew exploration vehicle
***Advanced power and propulsion**:* Primarily nuclear thermal and nuclear electric, to enable spacecraft and instrument operations and communications, particularly in the outer solar system, where sunlight can no longer be exploited by solar panels
***Cryogenic fluid management**:* Cooling technologies for precision astronomical sensors and advanced spacecraft, as well as propellant storage and transfer in space
***Large aperture systems**:* For next-generation astronomical telescopes and detectors.
***Formation flying**:* For free-space interferometric applications and near-surface reconnaissance of planetary bodies
***High bandwidth communications**:* Optical and high-frequency microwave systems to enhance data transmission rates.
***Entry, descent, and landing**:* Precision targeting and landing on "high-g" and "low-g" planetary bodies.
***Closed-loop life support and habitability**:* Recycling of oxygen, carbon dioxide, and water for long-duration human presence in space.
***Extravehicular activity systems**:* The spacesuit for the future, specifically for productive work on planetary surfaces.
***Autonomous systems and robotics**:* To monitor, maintain, and where possible, repair complex space systems.
***Scientific data collection/analysis**:* Lightweight, temperature-tolerant, radiation-hard sensors.
***Biomedical risk mitigation**:* Space medicine; remote monitoring, diagnosis and treatment
***Transformational spaceport and range technologies**:* Launch site infrastructure and range capabilities for the crew exploration vehicle and advanced heavy lift vehicles.
***Automated rendezvous and docking**:* For human exploration and robotic sample returns
***Planetary in situ resource utilization**:* Ultimately enabling us to "cut the cord" with Earth for space logistics.

Capability Roadmap Team Schedule (October 27, 2004)



Red Milestones and red cross hatched bars indicate schedule slips

Roles & Responsibilities for Capability Roadmap Development (cont)

- **There are three key positions on the individual capability roadmap teams**
  - **NASA Chair**
    - Leading the team of internal NASA and external members
    - Selection of team members, including the external Chair, in coordination with the Mission Directorate Coordinator
    - Development of a detailed schedule and delivery of the capability roadmap products
    - Serving as a consultant to the integration team that will tie both the strategic and capability roadmaps into an integrated Agency architecture
  - **External Chair**
    - Co-leading of the team of internal NASA and external members
    - Assisting the NASA Chair in selection of external team members
  - **APIO Roadmap Coordinators**
    - Coordinating with the Mission Directorate Coordinator to ensure that the roadmap is prepared within the APIO guidelines, overall schedule, and constraints
    - Serving as a member of the roadmap team to maintain technical insight into the roadmap as it develops so that he/she can serve as a member of the Integration Team that will tie both strategic and capability roadmaps into an integrated Agency architecture
    - Responding to requests for information from the roadmap team to the APIO
    - Assisting the NASA Chair in the clarification of process, and product guidance by working with APIO lead and Mission Directorate Coordinators
    - Assisting the NASA Chair in working issues that arise between capability roadmaps
    - Keeping APIO management informed

Space Communication & Navigation Roadmap Charter

Develop a capability roadmap for Space Communications and Navigation in support of the NASA Strategic Plan and Strategic Roadmaps that enables the associated missions to meet their specific objectives

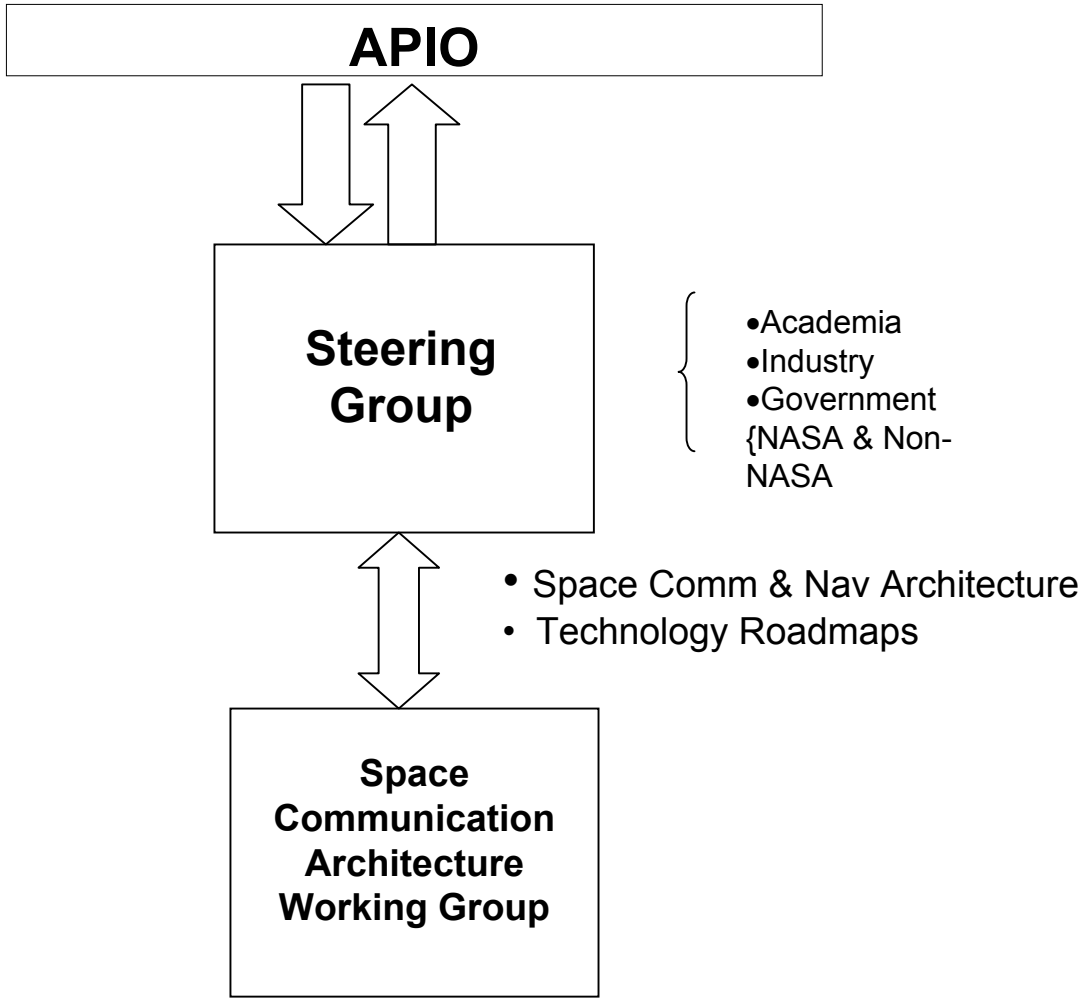
Roadmap Relevance

Space Communications and Navigation capabilities are essential to the conduct of all space operations.

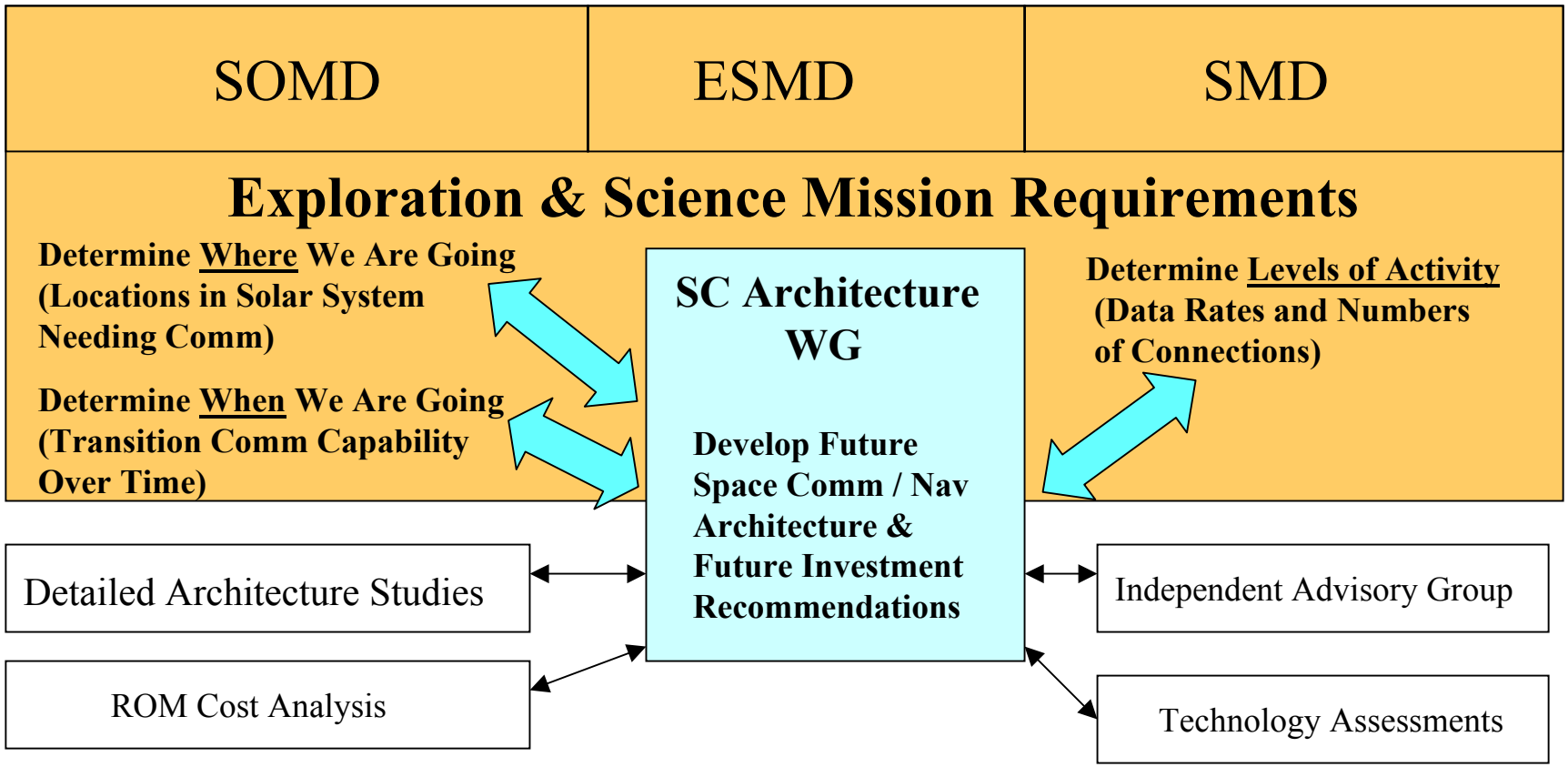
Key Elements of the Vision and Relevancy of Comm/Nav

- Objectives
  - Implement a sustained and affordable human and robotic program
  - Extend human presence across the solar system and beyond
  - Develop supporting innovative technologies, knowledge, and infrastructures
  - Promote international and commercial participation in exploration
- All the above objectives require communications and navigation.
- Major Milestones
  - 2008: Initial flight test of CEV
  - 2008: Launch first lunar robotic orbiter
  - 2009-2010: Robotic mission to lunar surface
  - 2011 First Un-crewed CEV flight
  - 2014: First crewed CEV flight
  - 2012-2015: Jupiter Icy Moon Orbiter (JIMO)/Prometheus
  - 2015-2020: Human mission to return to the Moon

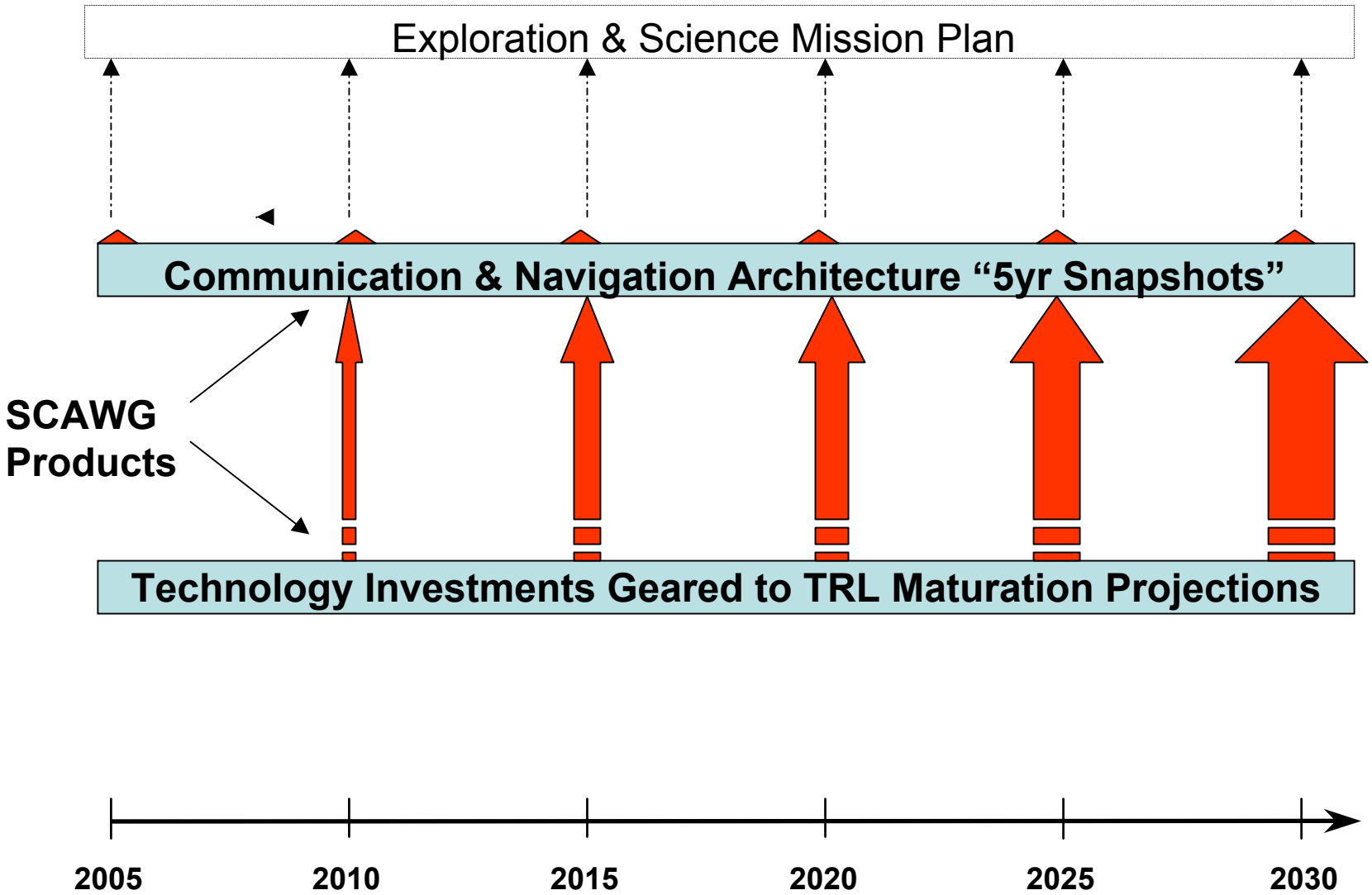
Space Communications and Navigation Capability Roadmap Development



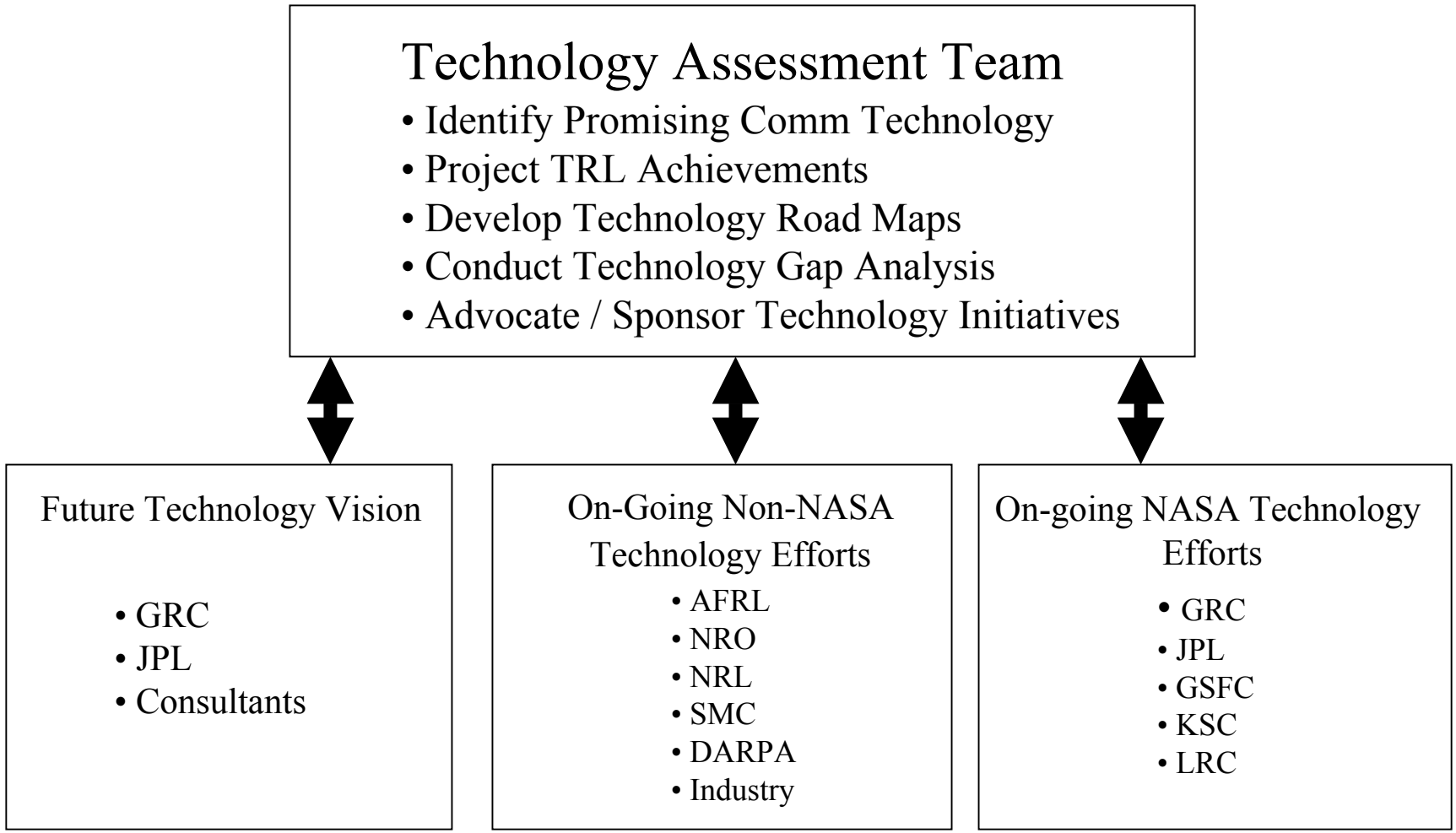
Space Communications Architecture Working Group



SCAWG Products



Space Communication Technology Assessment Team



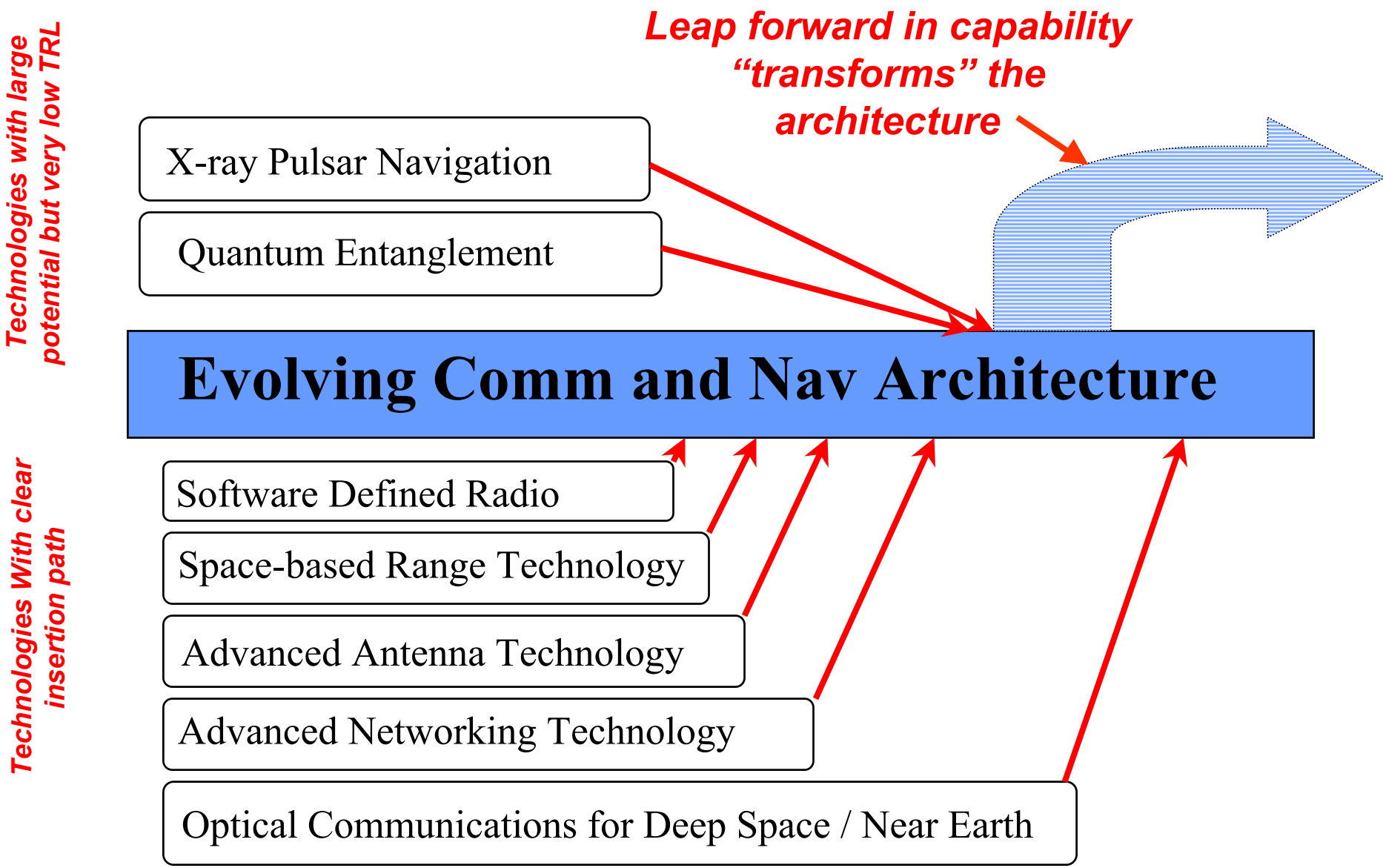
Technology Assessment

- Identify What Future Technology Advances May Enhance Comm & Nav Architecture Capability in the Future
- Project TRL Advancement to Determine When Available for Infusion Into Architecture
- Consider NASA, Other US Government, and Commercial Technology Developments

Working Group RFI

- SCAWG Issued RFI to Support Architecture and Technology Development
  - Addressed Points of Interest to SCWAG Effort Only
  - Sought Information on Advanced Communication Technology and Architecture
  - Some Redundancy with APIO RFI
- Numerous Responses
- Respondents Invited to Brief Full Working Group
  - Two Invitees at Each Major WG Meeting
  - WG CS Members and Support Contractors (with Signed NDAs)
  - Briefings Still in Process
  - Numerous Interesting Concepts / Valuable Information

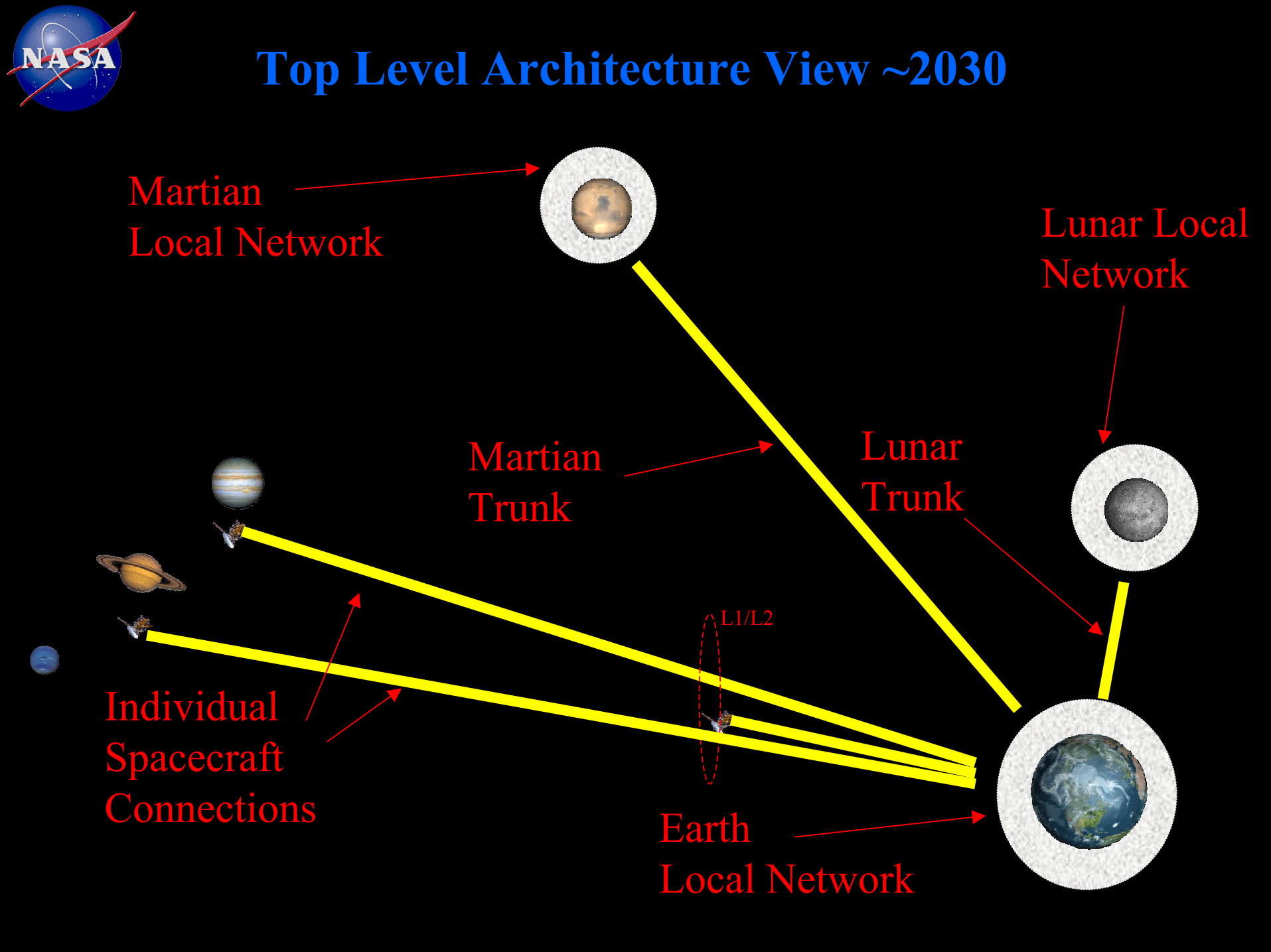
Example Technology Considerations



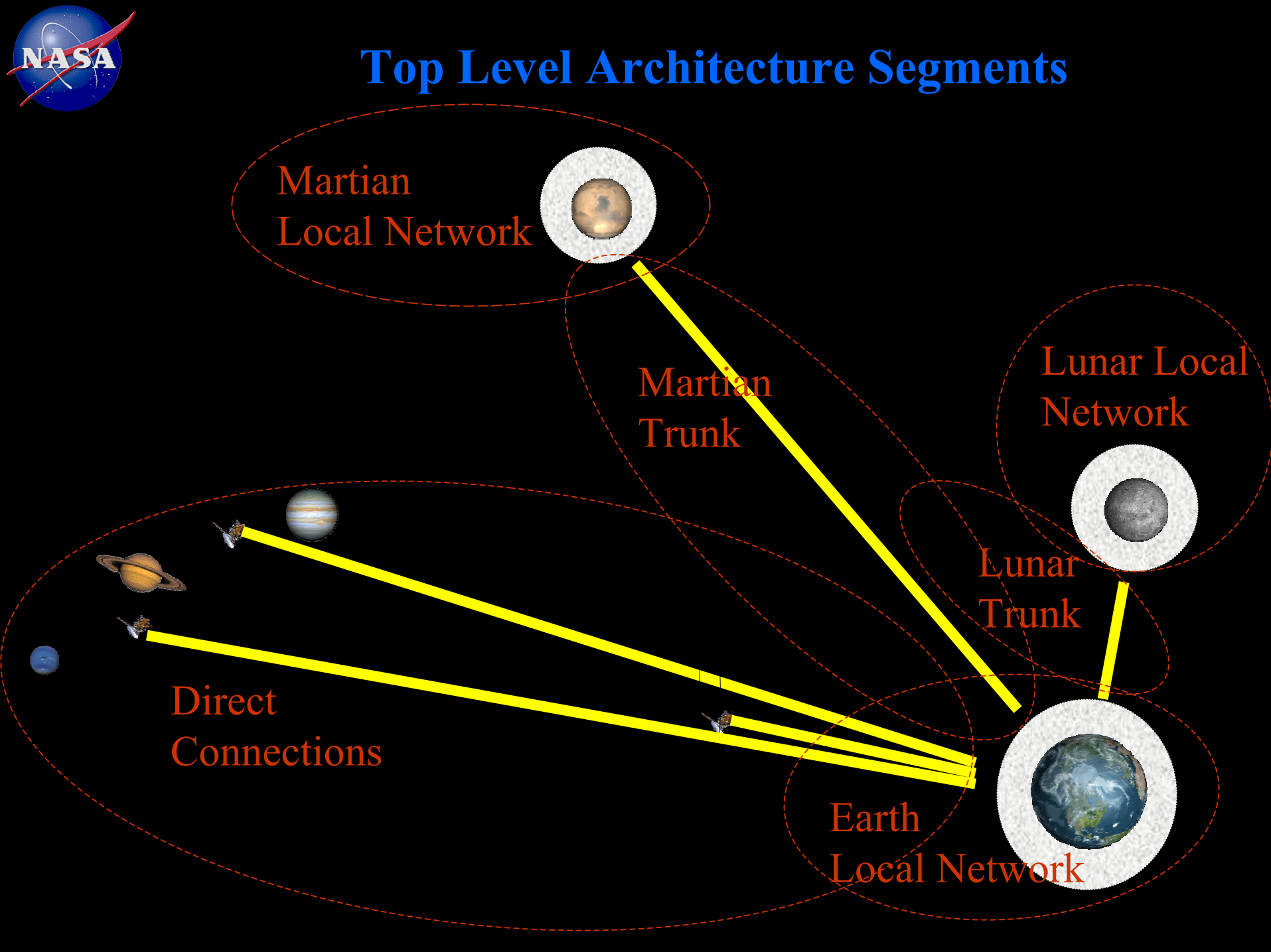
External NASA Considerations

- Other Agency Architecture Work & Agreements
  - SATOPS Transition to USB and SLE
  - Transformational Communications Architecture (TCA)
- Other Agency Space Communications Technology Work & Agreements
  - High Rate Communication Links
  - Space Navigation Technology Initiatives
- International Space Agency Interoperability
  - Spectrum
  - Interoperable Communication Protocols
- Industry
  - Technology
  - Services

Top Level Architecture View ~2030



Top Level Architecture Segments



Work Breakdown Structure

1.0 Mission Scenarios

- 1.1 Earth Orbiting
- 1.2 Cis-lunar
- 1.3 Lunar
- 1.4 Mars
- 1.5 Inter-planetary

2.0 Operations Concepts

- 2.1 Tracking, Telemetry and Command (TT&C)
- 2.2 Launch
  - 2.2.1 Range Safety
  - 2.2.2 TT&C
- 2.3 Mission data-Real time and Delayed
- 2.4 Flight dynamics-Orbits and trajectories
- 2.5 Surface comm/nav
- 2.6 Autonomy
- 2.7 Connectivity-simultaneous operations
- 2.8 Security
- 2.9 Interoperability
- 2.10 Anomaly Operations

3.0 Architectures

- 3.1 Topology
  - 3.1.1 Orbital Configuration
  - 3.1.2 Surface sites
- 3.2 Spectrum
  - 3.2.1 Near-earth
  - 3.2.2 Deep Space
  - 3.2.3 In-situ
- 3.3 Bandwidth
  - 3.3.1 Earth Orbiting
  - 3.3.2 Cis-lunar
  - 3.3.3 Lunar
  - 3.3.4 Mars
  - 3.3.5 Deep Space
- 3.4 Connectivity
  - 3.4.1 Individual
  - 3.4.2 Simultaneous
- 3.5 Networks
  - 3.5.1 Earth Orbital
  - 3.5.2 Lunar
  - 3.5.3 Mars

Work Breakdown Structure (cont)

4.0 Key Enabling Technologies

- 4.1 Optical comm.
- 4.2 High power transmitters
  - 4.2.1 Space to Earth
  - 4.2.2 Earth to Space
- 4.3 Software Radios
- 4.4 High Performance Antennas
- 4.5 Spectrum Efficiency
  - 4.5.1 Bandwidth Efficient Modulation
  - 4.5.2 Coding
  - 4.5.3 Compression
- 4.6 Space Based Navigation
- 4.7 Networking
- 4.8 Timing

5.0 Capabilities Timeline to 2030

- 5.1 Earth Orbiting
- 5.2 Lunar
- 5.3 Mars
- 5.4 Deep Space

6.0 Investment Schedule

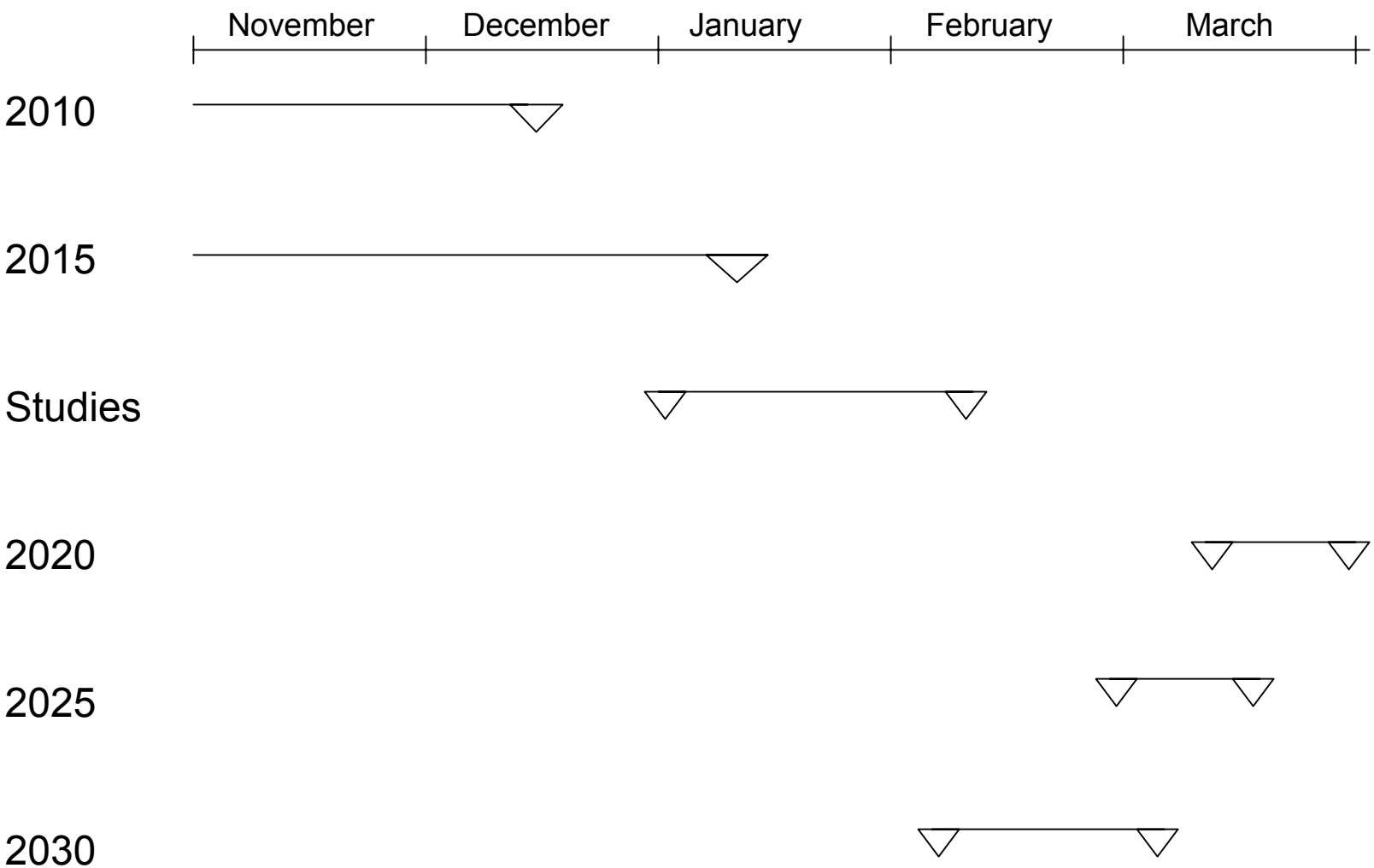
- 6.1 Technologies
- 6.2 Systems Acquisition

Working Group Progress to Date

Time Frame	Earth	Earth/Moon Trunk	Moon	Earth/Mars Trunk	Mars
2010	D	X	X	X	X
2015		D	X	D	
2020					
2025					
2030					

X = Complete 1st Spiral
D = Underdevelopment

Architecture Snapshot Development Plan



Focused Studies

- Optical Comm for Deep Space vs Ka-band
  - Supportable Data Rates
  - Relative User Burden
- Best Location for Deep Space Optical Comm Near Earth Receivers
- Role of Software Defined Radio in Architecture
- Role of GPS & Future Space-based PNT Systems in Near Earth Position & Nav
- Future Earth Relay Need Assessment & Potential Configurations
- When Ka-band Arrayed Antenna Transmit Capability Available

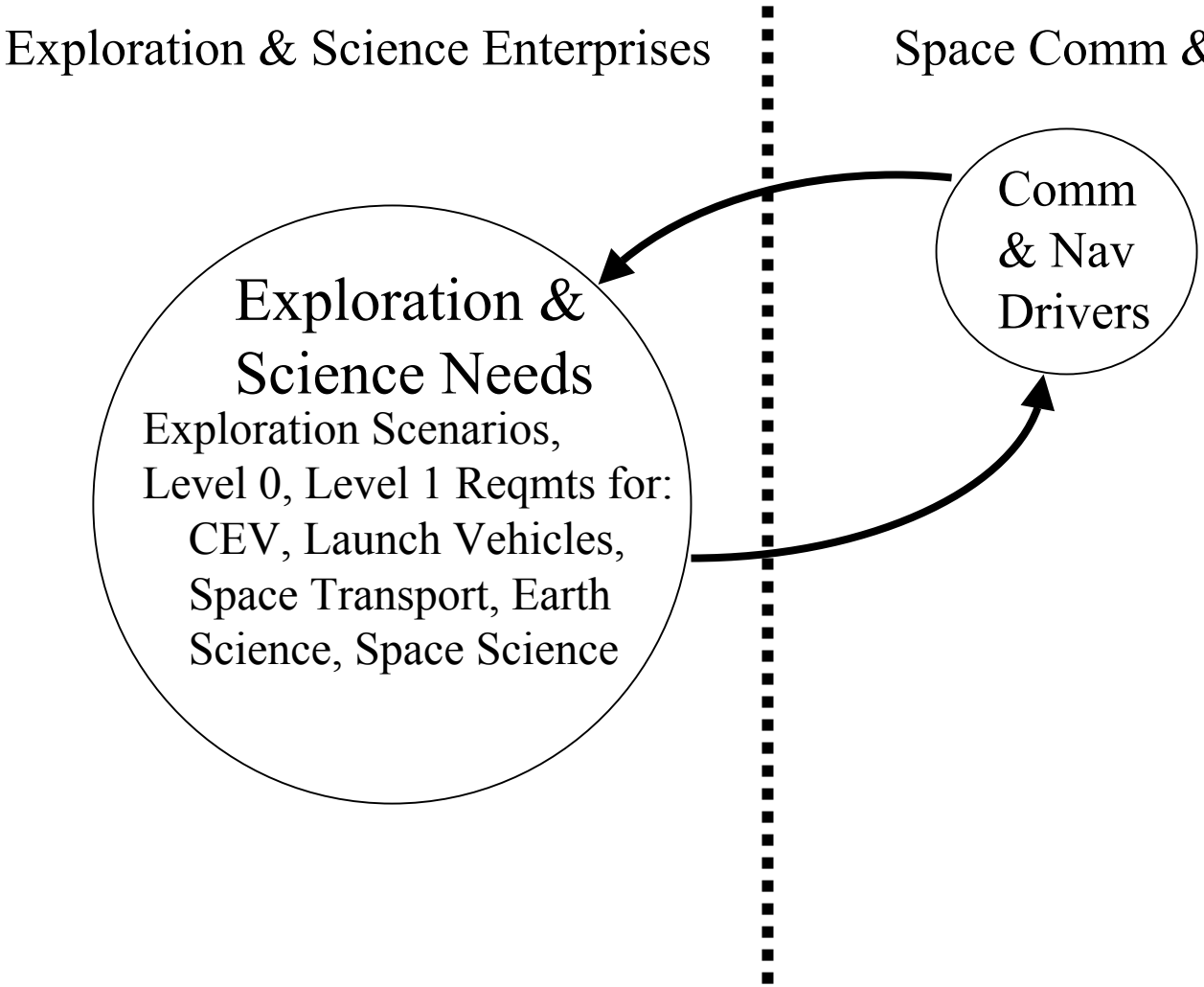
Summary of White Papers

- 17 white Papers Received
- 15 Organizations Represented
- 10 Non-NASA Organizations Represented
- Topics Include:
  - Basic Architecture Considerations
  - Optical Communications
  - Networking & Protocols

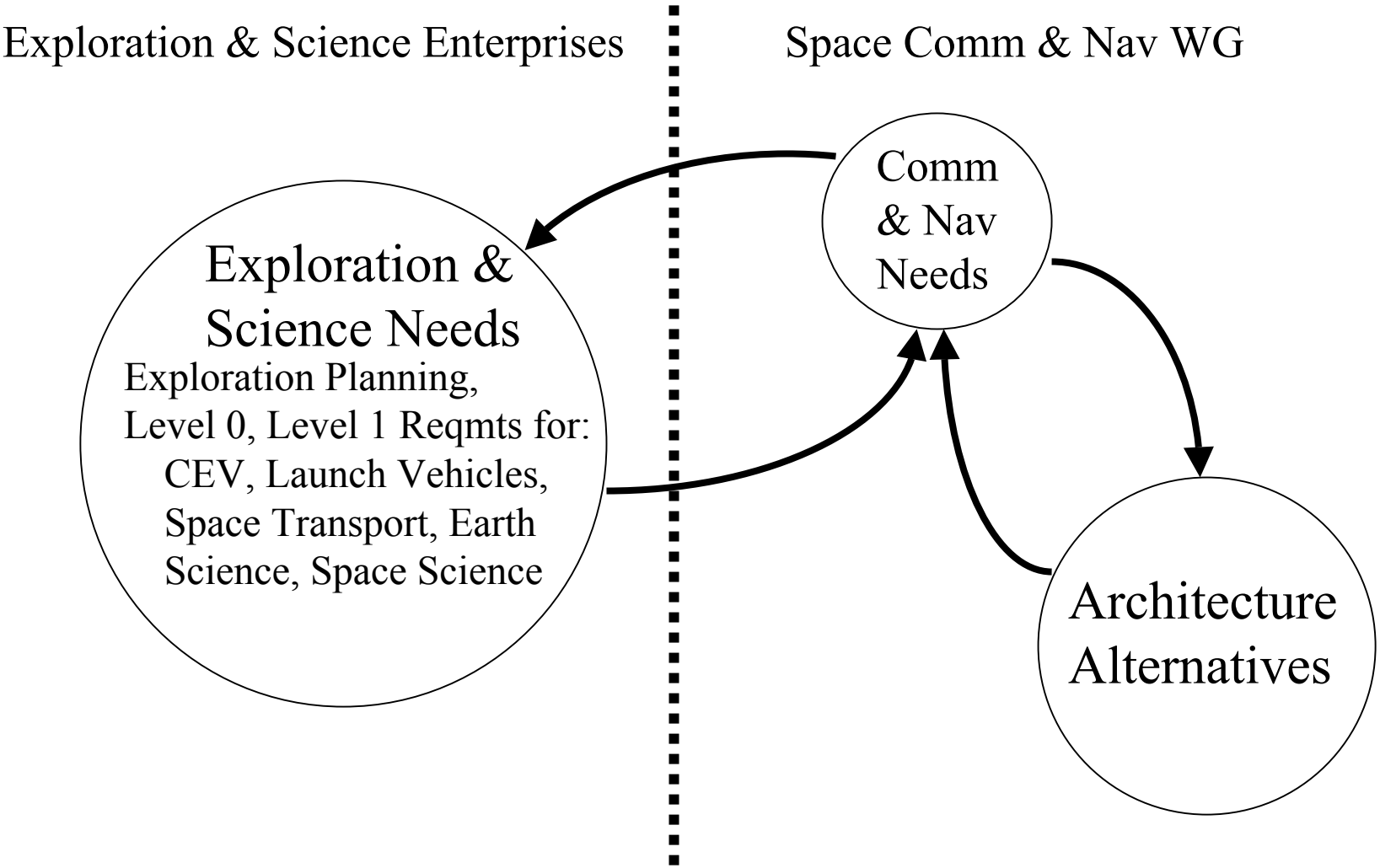
Backup Slides

Process

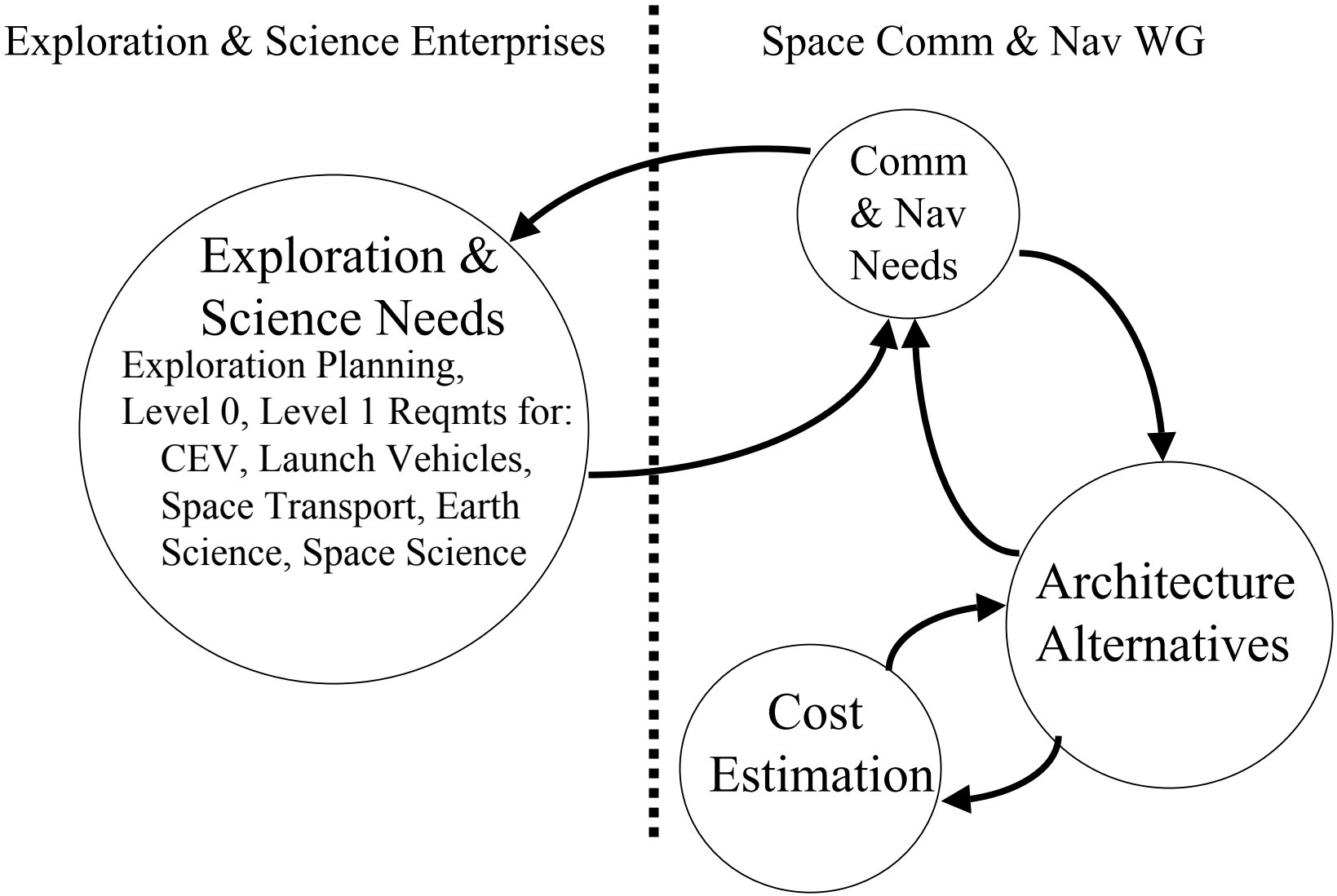
Identify Comm & Nav Drivers



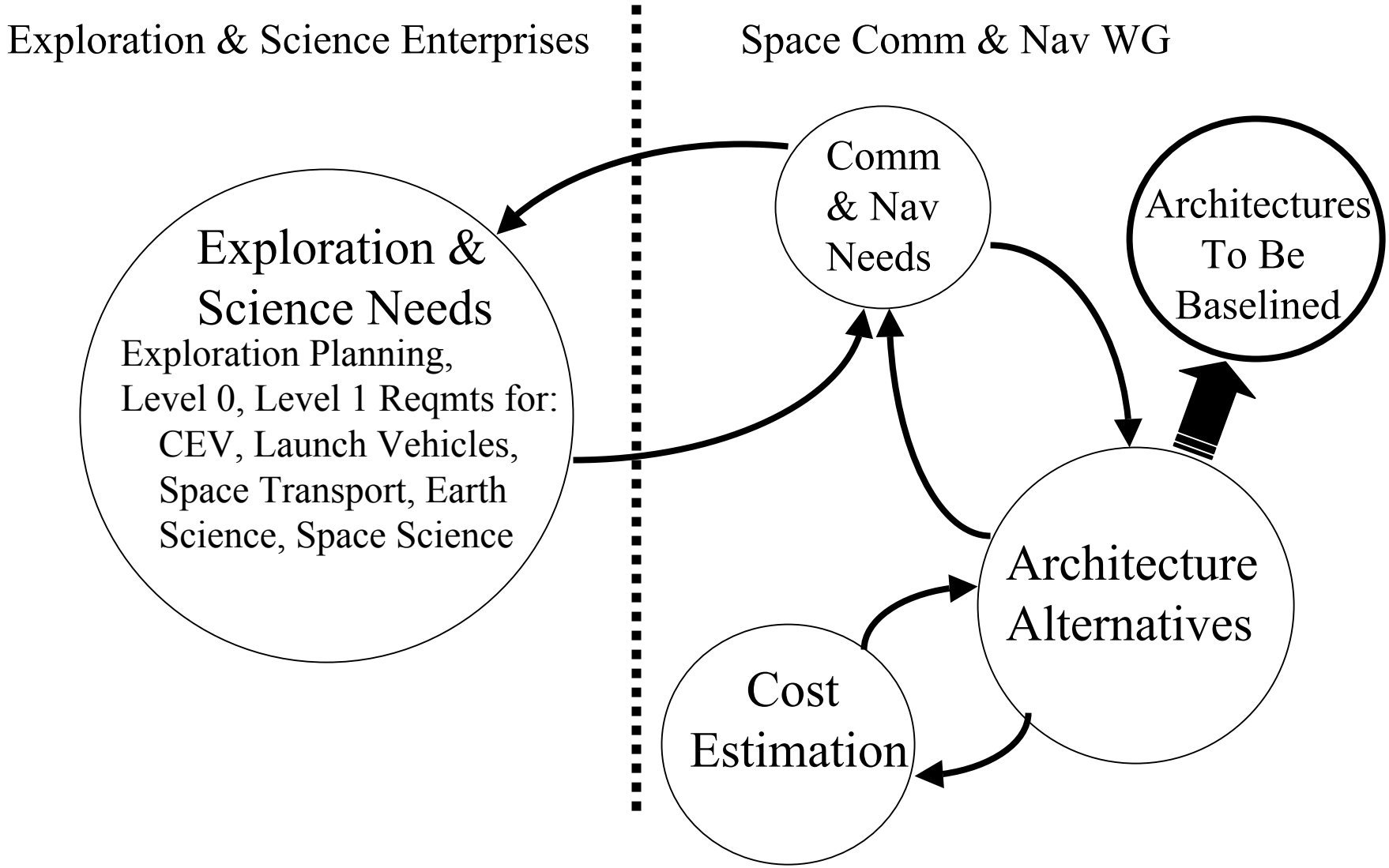
Develop Architecture Alternatives

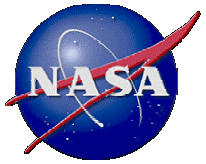


Perform Cost Benefits Analysis



Select Architectures





Architecture Definition

Architecture: the structure of components,
their relationships, and
the principles and guidelines
governing their design and
evolution over time.

Space Communications Architecture Working Group

	Name	Center and Organization	Phone	E-mail	
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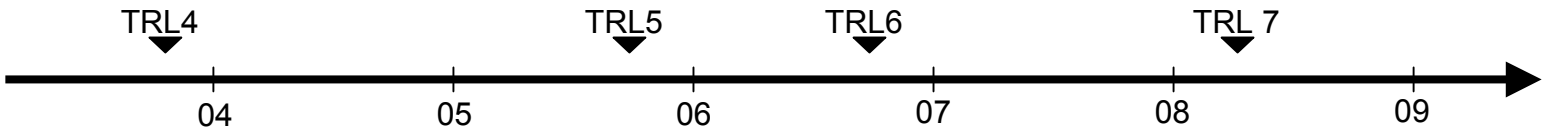
Space- Based Range Technology Example of TRL Projection

Project Goals: Develop, prototype, and demonstrate space-based communication technologies

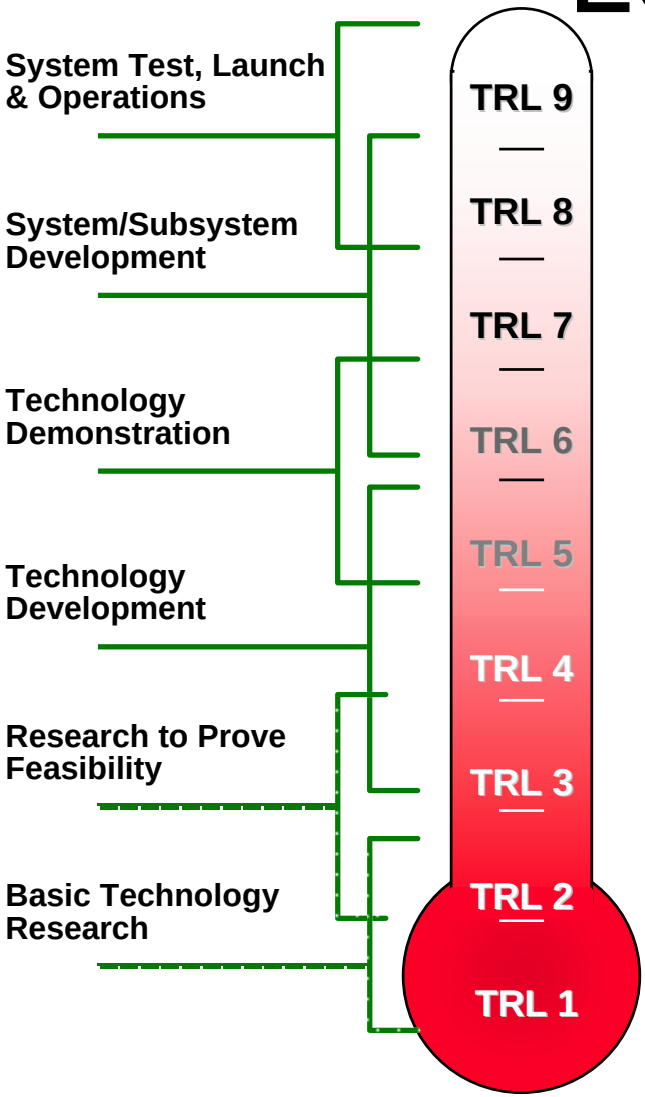
Benefits: Provide reduced cost and improved performance for future space launch ranges & launch and flight vehicle operations



Estimated Technology Readiness Level Timeline, calendar years

Autonomous Flight Safety System

NASA Technology Readiness Levels (TRL)



TRL 9 — Actual system "flight proven" through successful mission operations

TRL 8 — Actual system completed and "flight qualified" through test and demonstration (Ground or Flight)

TRL 7 — System prototype demonstration in a space environment

TRL 6 — System/subsystem model or prototype demonstration in a relevant environment (Ground or Space)

TRL 5 — Component and/or breadboard validation in relevant environment

TRL 4 — Component and/or breadboard validation in laboratory environment

TRL 3 — Analytical and experimental critical function and/or characteristic proof-of-concept

TRL 2 — Technology concept and/or application formulated

TRL 1 — Basic principles observed and reported